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Monitoring Completed Navigation Projects, Lessons Learned V

by Robert R. Bottin, Jr.

PURPOSE: The Coastal and Hydraulics Engineering Technical Note (CHETN) herein provides a summary of lessons learned and significant results for projects monitored under the Monitoring Completed Navigation Projects (MCNP) Program.

GENERAL: This CHETN is the fifth of a series summarizing lessons learned and project results from the MCNP Program, formerly the Monitoring Completed Coastal Projects Program. Lessons learned from previously monitored projects may be obtained from USACE (1992); USACE (1993); Bottin (1997); and Bottin (2000). This CHETN covers three comprehensively monitored projects for which reports have been prepared: "Boston Harbor Confined Aquatic Disposal Cells, MA" (Hales 2001); "Marseilles Dam submersible gates, IL" (Cooper et al. 2001); and "Morro Bay Harbor entrance, CA" (Thompson, Bottin, and Shak 2002). The CHETN also includes four projects monitored under the "Periodic Inspections" Work Unit of the MCNP Program: "St. Paul Harbor breakwater, AK" (Bottin and Jeffries 2001); "Nawiliwili Harbor breakwater, HI" (Bottin and Meyers 2002a); and Kahului and Laupahoehoe breakwaters, HI (Bottin and Meyers 2002b).

The elements of the comprehensively monitored projects included the measurement of water quality of suspended solids, contaminated dredged material consolidation, and dredged cell cap erosion at Boston Harbor; life-cycle cost analysis, vibration data for submergible spillway gates, videotape analysis of ice passage, and analysis of dam remote operating system at Marseilles lock and dam; and waves, water levels, tidal currents and elevations, and bathymetry data at Morro Bay Harbor entrance. Elements of the projects monitored under the "Periodic Inspections" Work Unit involved predominantly photogrammetric surveys and analyses of structures, with limited ground truthing surveys, and broken armor unit inspections.

COMPREHENSIVELY MONITORED PROJECTS:

Boston Harbor Confined Aquatic Disposal Cells, Massachusetts. The Boston Harbor Navigation Improvement Project involves maintenance dredging of the main ship channel, tributary channels, and associated berthing areas. Lack of an upland disposal site and denial of approval to place contaminated sediments at an open-water site resulted in the decision to use in-channel confined aquatic disposal (CAD) cells for placement of dredged materials. Monitoring, performed during the period June 1999-March 2001, was composed of three primary activities: (a) water quality monitoring of suspended solids near the operation of two environmentally-sensitive clamshell dredge buckets and one normal clamshell bucket, to document the benefits of the special clamshell buckets, (b) monitoring contaminated dredged material consolidation and strength prior to and after placement of the sand cap, and (c) developing cap erosion predictions from both tidal currents and ship propeller wash to characterize the likely amount of cap damage to be expected from either source. Lessons learned and significant results are presented as follows:

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a. Sediment resuspension was studied for a conventional clamshell dredge bucket (open-faced), an enclosed clamshell bucket, and a CableArm bucket. Near field results indicated that turbidity was 46 percent less for the CableArm bucket than the conventional clamshell bucket. Turbidity for the enclosed bucket, however, was 79 percent less than that observed for the conventional bucket in the near field. Far field data results, although difficult to track and measure, corresponded to those data collected in the near field.

b. The natural cohesion and strength of sediments were altered by the dredging process, resulting in sediments in the CAD cell that were unstable due to high water content and low shear strength. Observations indicated that extending the dredged material sediment consolidation period prior to capping would allow the sediment shear strength to increase sufficiently to adequately resist the superimposed cap weight.

c. Analytical modeling of a CAD cell was conducted as part of the monitoring. The deformation pattern indicated the principal plane of shear developed along the base of the CAD cell rather than within the fill material suggesting that the size and shape of the cell bottom controlled the critical shear surface.

d. From analytical modeling results, an undrained shear strength of about 956.48 Pa (20 lb/ft^2) was determined a reasonable criteria for dredged material strength prior to capping. Physical modeling of the CAD cell in the geotechnical centrifuge with an undrained shear strength between 957.60 Pa (20 lb/ft^2) and 1,436.40 Pa (30 lb/ft^2) confirmed that the sand cap would remain stable although settlement was observed in the sand surface.

e. Monitoring indicated that bottom sediments are temporarily resuspended during the passage of large vessels, however, the volume of sediments resuspended from both capped and uncapped CAD cells is very small. The resuspended sediments also settled to the seafloor with 1 hr of suspension. It was also determined that tidal currents within the harbor were insufficient to induce major erosion of bottom sediments within the CAD cells.

Marseilles Dam, Illinois River, Illinois. Marseilles Dam, located on the Illinois River near the city of Marseilles, IL, was monitored during the period June 1999-June 2001. Monitoring was performed to determine if submersible tainter gates were performing (both functionally and structurally) as predicted by a physical model study used in project design. The efficiency of a remote operation system to maintain pool levels between the lock and dam was also monitored. The monitoring study included a life-cycle cost analysis, measurements of gate vibrations, and a videotape analysis to analyze gate efficiency for ice passage. Lessons learned and significant results are presented as follows:

a. The submersible gates at Marseilles Dam have greatly improved winter operation. Submerging the gates during cold, low flow periods, with periodic cycling, eliminates freezing in the gates and the need for personnel to be onsite. The costs and hazards of chipping, or thawing the gates with steam, have been eliminated by the new gate design.

b. The gates effectively pass fragmented floes and loose brash in the submerged mode without loss of pool elevation, or scour damage to the downstream channel for typical winter

discharges. To pass heavy brash, however, it is necessary to concentrate the flow by opening only one or two gates in the raised mode.

c. Although ice formation near the dam was very light during the monitoring period, the videotape used to analyze ice passage was successful. The technique is relatively low cost, logistically simple, and provides a valuable visual record for analysis of the efficiency of the gates to pass ice in the submerged mode.

d. During spring, summer, and fall, flow releases from the dam are performed with the gates operated in the raised position; and during winter months, the gates generally are operated in the submerged position. Vibration levels measured for both raised and submerged gate operational conditions were extremely small. Maximum vibration level values and displacement observed for raised gate conditions were 0.2 g's and 0.005 cm (0.002 in.), respectively. For submerged gate positions, maximum vibration levels and displacements were less than 0.3 g's and less than 0.002 cm (0.001 in.), respectively. The monitoring indicates the gates are functioning essentially vibration-free which validates the physical model study performed previously.

e. A life-cycle cost analysis was conducted for three alternatives identified for operation of the Marseilles Dam: maintenance of existing remote operation; manual operation; and replacement of the remote operation system. Based on the analysis, the most cost-efficient alternative for dam operation is maintenance of the existing remote operation system.

f. The remote operation system eliminated the need for 24-hr staffing of the dam and provides for operation of the dam at the lock 3.86 km (2.4 miles) away. Monitoring results indicated the remote operation system met tight pool tolerance constraints required for navigation.

Morro Bay Harbor Entrance, California. Morro Bay Harbor Entrance, located on the central coast of California about midway between Los Angeles and San Francisco, was monitored during the period January 1998-August 2001. Monitoring was performed to determine if nonstructural modifications at the harbor entrance were performing as predicted. Evaluation of hydrodynamic conditions and sedimentation rates in the harbor entrance as well as validation of physical and numerical models used as design tools were conducted. Wave data (both inside and outside the harbor entrance), tidal elevations and currents, and bathymetry were obtained to determine design effectiveness of the harbor entrance alternative. Limited ground-based surveys and photogrammetric flights of the existing south breakwater also were obtained to determine if any negative impacts had occurred as a result of the dredging improvements. Lessons learned as well as significant results are presented as follows:

a. The deepened, expanded entrance channel at Morro Bay Harbor resulted in a reduction of hazardous breaking wave conditions and significantly improved navigation conditions in the harbor entrance.

b. Prototype wave data measured in the harbor entrance and within the entrance channel were comparable to those obtained in the physical model investigation for similar incident wave conditions.

c. The numerical model, Harbor, Deep Water (HARBD) as applied in the original study, overestimated wave heights throughout the Morro Bay entrance channel. The lack of wave breaking and the use of monochromatic waves were major limitations and probably contributed to the overprediction of wave heights.

d. The most current numerical model for harbor wave modeling, CGWAVE, was activated and run as part of the monitoring study. CGWAVE results are much more comparable to field and physical model wave heights and much improved over the original HARBD model.

e. Bathymetry surveys at Morro Bay were conducted 11 times during the monitoring study. Analysis of these data revealed seasonal influences on shoaling rates in the entrance. During survey intervals encompassing winter months, significant shoaling occurred, particularly after stormy periods. In contrast, intervals covering predominantly summer months revealed slight bathymetric change in most areas. Data also indicated that shoaling rates elevated immediately after dredging as material was more effectively trapped in deep excavation areas.

f. Predictions of sedimentation rates in Morro Bay entrance were very reasonable in comparison to shoaling rates observed during monitoring. It was anticipated that improvements could be effectively maintained with a 3-year dredging interval in the entrance. To consistently preserve benefits of the deepened channel, the monitoring study suggested that a 3-year dredging interval is a maximum.

g. The physical model study qualitatively predicted wave-driven sediment transport paths and deposition patterns. In general, shoaling patterns observed in the prototype were similar qualitatively to those predicted by the physical model. Sediment moved into the entrance channel from the south and a transport path continued around the south breakwater head and into the sand trap area.

h. Physical model experiments indicated that the south breakwater head could experience a more severe wave climate with the modified entrance in place, as opposed to preproject conditions. Based on design conditions, the breakwater was predicted to be unaffected by the increase in wave heights. Photogrammetric surveys of the above-water portion of the south breakwater during the monitoring period revealed no significant changes. The structure, however, should continue to be monitored on a periodic basis and inspected after major storm events.

PERIODIC INSPECTION PROJECTS: Selected coastal structures are periodically monitored to gain an understanding of their long-term structural responses to their environments. In general, relatively low-cost remote sensing tools and techniques, with limited ground truthing surveys, are the primary inspection methods used in the monitoring efforts. Photogrammetric analysis has proven to be an excellent tool in obtaining very precise positions of above-water armor units on the structures monitored. Since the last MCNP lessons learned CHETN was published, breakwaters at St. Paul Harbor, AK, and Nawiliwili Harbor, Kahului Harbor, and Laupahoehoe boat-launching facility, HI, have been revisited through the periodic inspection work unit to determine their performances over a period of time. Lessons learned and significant results for these projects are presented as follows:

St. Paul Harbor breakwater, Alaska. Monitoring data for the period 1996-2000 were analyzed for the St. Paul Harbor outer breakwater. This is a rubble-mound structure armored with 16,330-kg (18-ton) stone along the trunk and 21,770-kg (24-ton) stone around the breakwater head. Work entailed reestablishing targets, conducting limited ground-based surveys, aerial photography, and photogrammetric analysis of the breakwater for comparison with data obtained in 1996. The entire above-water armor unit field was analyzed and quantified through the use of high resolution, aerial stereo pair photographs, a stereoplotter, and Intergraph-based software. A detailed broken armor unit survey also was conducted during the effort and compared to previous survey data.

Results of the 2000 monitoring effort indicated essentially no change in the overall breakwater crest elevation and shape of the structure since the 1996 survey. Although still below design elevation, the structure had not, in general, settled or subsided to any great extent during the period. There were localized areas in the breakwater, however, where voids had occurred (due to the displacement of armor stones). Voids were noted on both sea-side and harbor-side slopes of the structure as well as the breakwater crest.

A total of 221 broken armor stones was documented during the survey versus 230 in 1996. Analysis indicated that 33 broken stones, documented in the 1996 survey, could not be found during 2000, suggesting they may have been moved away by wave and/or ice action. The rate of stone breakage appears to have declined from the previous survey period. Only 24 new broken armor stones occurred in the past 4-year period versus 157 broken stones that occurred during the 1993-1996 time frame. As noted on the contour maps and breakwater cross sections developed through photogrammetry, voids due to displaced stones were visually observed in localized areas of the breakwater during the broken stone inventory.

The St. Paul Harbor breakwater is functioning in an acceptable manner, with the exception of excessive overtopping, and is considered to be in good condition. To minimize breakwater damage and reduce overtopping, the construction of three submerged reef breakwaters seaward of the structure was initiated during the 2000 construction season. The photogrammetry conducted in 2000 not only quantified changes in the armor unit field since the previous study in 1996, but established new base conditions for the breakwater upon which the performance of the reef breakwaters can be evaluated in future years.

Nawiliwili Harbor breakwater, Hawaii. Monitoring data for the period 1995-2001 were analyzed for the Nawiliwili Harbor breakwater. This is a complex rubble-mound structure armored with several sizes of dolos and tribar concrete armor units. Included are 9,980-kg (11-ton) and 20,865-kg (23-ton) dolos and 5,900-kg (6.5-ton) and 16,150-kg (17.8-ton) tribars. Work involved reestablishing targets, conducting limited ground-based surveys, aerial photography, and photogrammetric analysis for comparison with data obtained in 1995. The entire above-water armor unit field was analyzed and quantified through the use of high resolution, aerial stereo pair photographs, a stereoplotter, and MICROSTATION-based software. A detailed broken armor unit survey also was conducted during the effort and compared to previous data.

Results of the 2001 monitoring effort indicated negligible movement of the concrete armor units on the breakwater. Maximum movement of the targets established on the armor units in the horizontal and vertical directions, respectively, was 0.013 m (0.42 ft) and 0.137 m (0.45 ft); and the average movement of all horizontal and vertical targets was 0.03 m (0.1 ft) and 0.046 m (0.15) ft. Maximum

movement of the targeted armor unit centroids was 0.104 m (0.34 ft) and 0.113 m (0.37 ft) in the horizontal and vertical directions, respectively, while average movements were 0.027 m (0.09 ft) and 0.043 m (0.14 ft) in the horizontal and vertical directions.

A total of 70 broken/cracked concrete armor units were documented during the 1995 survey versus 77 broken/cracked units in 2001. High wave action during the 1995 inspection, however, prevented a close examination of armor units at the water's edge. Of the seven additional broken units in 2001, six were located along the water's edge and may have been overlooked in 1995 due to the high wave action. Therefore, it appears that minimal armor unit breakage occurred between 1995 and 2001. During the broken armor unit survey, it was noted that the older 16,150-kg (17.8-ton) tribars were showing major surface spalling of concrete, but this was not putting the structure in any danger of instability. Overall the structure is in good condition.

Kahului Harbor breakwaters, Hawaii. Monitoring data for the period 1993-2001 were analyzed for the Kahului Harbor breakwaters. These are complex rubble-mound structures armored with several sizes of dolos, tribar, and tetrapod concrete armor units. Included are 5,445-kg (6-ton), 18,145-kg (20-ton), and 27,215-kg (30-ton) dolos; 5,900-kg (6.5-ton), 8,165-kg (9-ton), 17,235-kg (19-ton), 31,750-kg (35-ton), and 45,360-kg (50-ton) tribars; and 29,940-kg (33-ton) tetrapods. Work involved reestablishing targets, conducting limited ground-based surveys, aerial photography, and photogrammetric analysis for comparison with data obtained in 1993. The entire above-waver armor unit field was analyzed and quantified through the use of high resolution, aerial stereo pair photographs, a stereoplotter, and MICROSTATION-based software. A detailed broken armor unit survey was also conducted during the monitoring effort.

Results of the 2001 monitoring indicated varying degrees of armor unit movement on the Kahului breakwaters as opposed to 1993 positions. On the east breakwater, one target moved about 0.9 m (3 ft) horizontally and another moved almost 1.5 m (5 ft) vertically. Both the units were located around the seaward head of the structure. The average movement of the targets, however, was on the order of about 0.15 m (0.5 ft). An evaluation of nontargeted units indicated several had changed horizontal positions (on the order of 0.3 to 0.9 m (1 to 3 ft)) also around the seaward quadrant of the head of the east breakwater. These units are intact, however, and continue to be functional. For the west breakwater, comparisons of target coordinates revealed relatively close agreement with those obtained in 1993. The average movement of all targets in both the horizontal and vertical positions was less than 0.015 m (0.5 ft). Considering the movements of the targeted armor units' centroids, average movements in both the horizontal and vertical directions were less than 0.18 m (0.6 ft) for the east breakwater and less than 0.12 m (0.4 ft) for the west breakwater.

A total of 29 broken/cracked armor units on the east breakwater and 58 on the west breakwater were identified during the 2001 survey. These data established a base from which to evaluate future breakage in subsequent surveys, since no thorough broken armor unit survey was conducted in 1993. Concentrations of broken 5,445-kg (6-ton) dolos were noted on the sea side of the east breakwater trunk, and concentrations of broken 27,215-kg (30-ton) dolos were noted on the sea side of the head of the west breakwater. The armor units were functional and no voids or breaches were noted in the breakwaters. The overall condition of both structures was considered good.

Laupahoehoe Boat-Launching Facility breakwater, Hawaii. Monitoring data for the period 1992-2001 were analyzed for the Laupahoehoe breakwater. This is a rubble-mound structure armored with 27,215-kg (30-ton) dolos. Work entailed reestablishing targets, conducting limited ground-based surveys, aerial photography, and photogrammetric analysis for comparison with data obtained in 1992. The above-water armor unit field was analyzed and quantified through the use of high resolution, aerial stereo pair photographs, a stereoplotter, and MICROSTATION-based software. An armor unit survey also was conducted.

Results of the 2001 monitoring effort indicated negligible movement of the concrete armor units on the breakwater compared with 1992 data. Average target movement in both the horizontal and vertical directions was less than 0.06 m (0.2 ft). Considering the positions of the targeted units' centroids, average movements in both the horizontal and vertical directions were around 0.03 m (0.1 ft). No broken/cracked armor units were found on the breakwater, and the structure was considered to be in excellent condition.

ADDITIONAL INFORMATION: For additional information contact Mr. Robert R. Bottin, Jr., MCNP program manager, Coastal Harbors and Structures Branch, Coastal and Hydraulics Laboratory, U.S. Army Engineer Research and Development Center, at 601-634-3827, FAX 601-634-4827, or e-mail *ray.r.bottin@erdc.usace.army.mil*. This CHETN should be cited as follows:

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Additional information on the MCNP Program may be found at: *http://chl.wes.army.mil/research/navigation/mcnp_site/default.htm*

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